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13. ABSTRACT *(Maximum 200 words)*

In this report account is presented of research carried out during the period December 1, 1999-November 30, 2002 under the sponsorship of the Air Force Office of Scientific Research under grant F49620-00-1-1-0125. Our research covered many areas of modem optical physics, especially wave propagation in random media, inverse scattering, coherence properties of light, correlation-induced spectral changes, partially coherent beams, focusing of waves of arbitrary state of coherence, partially coherent solitons, spreading of partially coherent beams in random media, diffraction tomography and singular optics with polychromatic light. We believe that of special significance are some new results that we have obtained concerning the propagation of partially coherent beams in the turbulent atmosphere. The results indicate that in certain situations it is preferable to employ partially coherent beams rather than fully coherent ones for communication, tracking and guiding, for example. These results are preliminary and we are pursuing the subject further. In the field of singular optics we have opened up a new direction for progress in the field by having shown that sonic new and unexpected effects take place in the neighborhood of phase singularities in optical fields, when the light is polychromatic rather than monochromatic (studied previously). Specifically we have demonstrated that drastic changes of the spectrum of light take place in the immediate vicinity of the singular points. The results of our investigations were reported in 43 publications. They are listed on pages 3 to 5. Summaries of these publications are given on pages 6 - 14. Scientists who have participated in this research are listed on page 15.

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SPATIAL - COHERENCE EFFECTS IN SPECTROSCOPY

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December 1, 1999 - November 30, 2002

Final Report

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I. INTRODUCTION

In this report account is presented of research carried out during the period December 1, 1999 – November 30, 2002 under the sponsorship of the Air Force Office of Scientific Research under grant F49620-001-1-0125.

Our research covered many areas of modern optical physics, especially wave propagation in random media, inverse scattering, coherence properties of light, correlation-induced spectral changes, partially coherent beams, focusing of waves of arbitrary state of coherence, partially coherent solitons, spreading of partially coherent beams in random media, diffraction tomography and singular optics with polychromatic light.

We believe that of special significance are some new results that we have obtained concerning the propagation of partially coherent beams in the turbulent atmosphere. The results indicate that in certain situations it is preferable to employ partially coherent beams rather than fully coherent ones for communication, tracking and guiding, for example. These results are preliminary and we are pursuing the subject further. In the field of singular optics we have opened up a new direction for progress in the field by having shown that some new and unexpected effects take place in the neighborhood of phase singularities in optical fields, when the light is polychromatic rather than monochromatic (studied previously). Specifically we have demonstrated that drastic changes of the spectrum of light take place in the immediate vicinity of the singular points.

The results of our investigations were reported in 43 publications. They are listed on pages 3 to 5. Summaries of these publications are given on pages 6 - 14. Scientists who have participated in this research are listed on page 15.

II. LIST OF PUBLICATIONS RESULTING FROM RESEARCH SUPPORTED BY GRANT F49620-001-1-0125 DURING THE PERIOD DECEMBER 1, 1999 - NOVEMBER 30, 2002

1. G. Gbur, D. James and E. Wolf, "Energy Conservation Law for Randomly Fluctuating Electromagnetic Fields", *Phys. Rev. E.* **59**, 4594-4599 (1999).

2. P. S. Carney, E. Wolf and G. S. Agarwal, "Diffraction Tomography using Power Extinction Measurements", *J. Opt. Soc. Amer. A* **16**, 2643-2648 (1999).

3. E. Wolf, T. Shirai, G. Agarwal and L. Mandel, "Storage and Retrieval of Correlation Functions of Partially Coherent Fields", *Opt. Lett.* **24**, 367-369 (1999).

4. G. Gbur, J. T. Foley and E. Wolf, "Nonpropagating String Excitations – Finite Length and Damped Strings", *Wave Motion* **30**, 125-134 (1999).

5. G. Gbur and E. Wolf, "Phase Conjugation with Random Fields and with Deterministic and Random Scatterers", *Opt. Lett.* **24**, 10-12 (1999).

6. G. Gbur and E. Wolf, "Determination of Density Correlation Functions From Scattering of Polychromatic Light", *Opt. Commun.* **168**, 39-45 (1999).

7. S. A. Ponomarenko and E. Wolf, "Coherence Properties of Light in Young's Interference Pattern Formed with Partially Coherent Light", *Opt. Commun.* **170**, 1-8 (1999).

8. P. S. Carney and G. Gbur, "Optimal Apodizations for Finite Apertures", *J. Opt. Soc. Am.* **16**, 1638-1640 (1999).

9. S. A. Ponomarenko and A. V. Shchegrov, "Spectral Changes of Light Produced by Scattering from Disordered Anisotropic Media", *Phys. Rev. E.* **60**, 3310-3313 (1999).

10. G. Gbur and K. Kim, "Quasi-Homogeneous Approximation for a Class of Three-dimensional Primary Sources", *Opt. Commun.* **163**, 20-23 (1999).

11. A. V. Shchegrov, D. Birkedal and J. Shah, "Monte Carlo Simulations of Ultrafast Resonant Rayleigh Scattering from Quantum Well Excitons: Beyond Ensemble Averaging", *Phys. Rev. Letts.* **83**, 1391-4 (1999).

12. A. T. Friberg, T. D. Visser and E. Wolf, "A Reciprocity Inequality for Gaussian Schell-model Beams and some of its Consequences", *Opt. Letts.* **25**, 366-368 (2000).

13. A. V. Shchegrov and E. Wolf, "Partially Coherent Conical Beams", *Opt. Lett.* **25**, 141-143 (2000).

14. E. Wolf, "Coherence of Two Interfering Beams Modulated by a Uniformly Moving Diffuser", *J. Mod. Opt.* **47**, 1569-1573 (2000).

15. S. Ponomarenko and E. Wolf, "Light Beams with Minimum Phase-space Product", *Opt. Letts.* **25**, 663-665 (2000).

16. G. Gbur and D. F. V. James, "Unpolarized Sources that Generate Highly Polarized Fields Outside the Source", *J. Mod. Opt.* **47**, 1171-1177 (2000).

17. A. V. Shchegrov, J. Bloch, D. Birkedal and J. Shah, "Theory of Resonant Rayleigh Scattering from Semiconductor Microcavities: Signatures of Disorder", *Phys. Rev. Letts.* **84**, 3478-3481 (2000).

18. T. Shirai and E. Wolf, "Transformation of Coherence and of the Spectrum of Light by a Moving Diffuser", *J. Mod. Opt.* **182**, 265-272 (2000).

19. A. V. Shchegrov, K. Joulain, R. Carminati and J.-J. Greffet, "Near-field Spectral Due to Electromagnetic Surface Excitations", *Phys. Rev. Letts.* **85**, 1548-1551 (2000).

20. G. P. Agrawal and E. Wolf, "Propagation–induced Polarization Changes in Partially Coherent Optical Beams", *J. Opt. Soc. Amer. A* **17**, 2019-2023 (2000).

21. T. Visser, A. T. Friberg and E. Wolf, "Phase-space Inequality for Partially Coherent Beams", *Opt. Commun.* **187**, 1-6 (2001).

22. S. Ponomarenko and E. Wolf, "Effective Spatial and Angular Correlations in Beams of any State of Coherence and an Associated Phase-space Product", *Opt. Lett.* **26**, 122-124 (2001).

23. G. Gbur, "Uniqueness of the Solution to the Inverse Source Problem for Quasi-homogeneous Sources", *Opt. Commun.* **187**, 301-309 (2001).

24. S. Ponomarenko, "Class of Partially Coherent Beams Carrying Optical Vortices", submitted to J. Opt. Soc. Amer. A **18**, 150 (2001).

25. G. Gbur and E. Wolf, "Relation Between Computed Tomography (CAT) and Diffraction Tomography", *J. Opt. Soc. Amer.* A **18**, 2132-2137 (2001).

26. S. Ponomarenko and E. Wolf, "Correlations in Open Quantum Systems and Associated Uncertainty Relations", *Phys. Rev. A* **63**, 1-5 (2001).

27. G. Gbur and E. Wolf, "The Rayleigh Range of Gaussian Schell-model Beams", *J. Mod. Opt.* **48**, 1735-1741 (2001).

28. A. T. Friberg, T. D. Visser, W. Wang and E. Wolf, "Focal Shifts of Converging Diffracted Waves of any State of Spatial Coherence", *Opt. Commun.* **196**, 1-7 (2001).

29. G. Gbur and E. Wolf, "The Rayleigh Range of Partially Coherent Beams", *Opt. Commun.* **199**, 295-304 (2001).

30. P. S. Carney and E. Wolf, "Power-extinction Diffraction Tomography with Partially Coherent Light", *Opt. Lett.* **26**, 1770-1772 (2001).

31. S. Ponomarenko, "Twisted Gaussian Schell-model Solitons", *Phys. Rev. E* **64**, 036618, 1-5 (2001).

32. S. Ponomarenko, "Linear Superposition Principle for Partially Coherent Solitons", *Phys. Rev. E.* **65**, 055601, 1-4 (2002).

33. G. Gbur, T. D. Visser and E. Wolf, "Anomalous Behavior of Spectra near Phase Singularities of Focused Waves", *Phys. Rev. Lett.* **88**, 013901, 1-4 (2002).

34. S. Ponomarenko and E. Wolf, "Universal Structure of Field Correlations within a Fluctuating Medium", *Phys. Rev. E.* **65**, 016602, 1- (2002).

35. T. Shirai and E. Wolf, "Spatial Coherence Properties of the Far Field of a Class of Partially Coherent Beams which have the same Directionality as a Fully Coherent Laser Beam", *Opt. Comm.* **204**, 25-31 (2002).

36. G. Gbur and E. Wolf, "The Spreading of Partially Coherent Beams in Random Media", *J. Opt. Soc. Amer. A* **19**, 1592-1598 (2002).

37. G. Gbur, T. D. Visser and E. Wolf, "Singular Behavior of the Spectrum in the Neighborhood of Focus", *J. Opt. Soc. Amer. A.* **19**, 1694-1700 (2002).

38. S. A. Ponomarenko, J.-J. Greffet and E. Wolf, "The Diffusion of Partially Coherent Beams in Turbulent Media", *Opt. Commun.* **208**, 1-8 (2002).

39. S. A. Ponomarenko and E. Wolf, "Spectral Anomalies in a Fraunhofer Diffraction Pattern", *Opt. Lett.* **27**, 1211-1213 (2002).

40. G. Gbur and E. Wolf, "Diffraction Tomography without Phase Information", *Opt. Letts.* **27**, 1890-1892 (2002).

41. E. Wolf and G. Gbur, "Determination of the Scattering Amplitude and of the Extinction Cross-section from Measurements at Arbitrary Distances from the Scatterer", *Phys. Letts. A* **302**, 225-228 (2002).

42. T. D. Visser, G. Gbur and E. Wolf, "Effect of the State of Coherence on the Three-Dimensional Spectral Intensity Distribution near Focus", *Opt. Commun.*, **213**, 13-19 (2002).

43. G. Gbur and E. Wolf, "Hybrid Diffraction Tomography without Phase Information", *JOSA A* **19**, 2194-2202 (2002).

III. LIST OF SUMMARIES OF PUBLICATIONS RESULTING FROM RESEARCH SUPPORTED BY GRANT F49620-001-1-0125 DURING THE PERIOD DECEMBER 1, 1999 - NOVEMBER 31, 2002

1. **G. Gbur, D. James and E. Wolf, "Energy Conservation Law for Randomly Fluctuating Electromagnetic Fields",** ***Phys. Rev. E.*** **59, 4594-4599 (1999).**

   An energy conservation law is derived for electromagnetic fields generated by any random, statistically stationary, source distribution. It is shown to provide insight into the phenomenon of correlation-induced spectral changes. The results are illustrated by an example.

2. **P. S. Carney, E. Wolf and G. S. Agarwal, "Diffraction Tomography using Power Extinction Measurements",** ***JOSA A*** **16, 2643-2648 (1999).**

   We propose a new method for determining structures of semi-transparent media from measurements of the extinguished power in scattering experiments. The method circumvents the problem of measuring the phase of the scattered field. We illustrate how this technique may be used to reconstruct both deterministic and random scatterers.

3. **E. Wolf, T. Shirai, G. Agarwal and L. Mandel, "Storage and Retrieval of Correlation Functions of Partially Coherent Fields",** ***Opt. Lett.*** **24, 367-369 (1999).**

   A new method is described for determining the two-point equal-time coherence function (the mutual intensity) and the two-point equal-time intensity correlation function of partially coherent fields. The method is reminiscent of conventional holography but differs from it in several important respects.

4. **G. Gbur, J. T. Foley and E. Wolf, "Nonpropagating String Excitations – Finite Length and Damped Strings",** ***Wave Motion*** **30, 125-134 (1999).**

   The existence of localized nonpropagating displacements of an infinite undamped string generated by a monochromatic driving force was recently demonstrated theoretically. In this paper the theory of these nonpropagating excitations is generalized to the cases of (1) strings of finite length, (2) damped strings of infinite length, and (3) strings of infinite length driven by a force whose oscillations have a finite bandwidth.

5. **G. Gbur and E. Wolf, "Phase Conjugation with Random Fields and with Deterministic and Random Scatterers",** ***Opt. Lett.*** **24, 10-12 (1999).**

   The theory of distortion correction by phase conjugation, developed since the discovery of this phenomenon many years ago, applies to situations when the field that is conjugated is monochromatic and the medium with which it interacts is deterministic. In this Letter a generalization of the theory is presented that applies to phase conjugation of partially coherent waves interacting with either deterministic or random weakly scattering nonabsorbing media.

6. **G. Gbur and E. Wolf, "Determination of Density Correlation Functions from Scattering of Polychromatic Light", *Opt. Commun.* 168, 39-45 (1999).**

   It is shown that for some many-particle systems with a high degree of symmetry, the density correlation function may be determined by measurements of the changes in the spectrum of polychromatic light scattered by the particles. The use of spectral measurements for such inverse problems may appreciably reduce the number of measurements required to uniquely determine the system structure.

7. **S. A. Ponomarenko and E. Wolf, "Coherence Properties of Light in Young's Interference Pattern Formed with Partially Coherent Light", *Opt. Commun.* 170, 1-8 (1999).**

   It has been shown not long ago that the spectrum of light in Young's interference pattern formed by partially coherent light differs, in general, from the spectrum of light incident on the pinholes; and, moreover, that the spectrum depends on the position of the point of observation. In this paper we extend the analysis by deriving expressions for the spectral degree of coherence and for the cross-spectral density of intensity fluctuations of the light at any pair of points in the interference pattern. We illustrate the general results by examples.

8. **P. S. Carney and G. Gbur, "Optimal Apodizations for Finite Apertures", *J. Opt. Soc. Am.* 16, 1638-1640 (1999).**

   A method is presented for determining the aperture apodization functions needed to optimize any given product of powers of the even-order moments of the beam intensity in the near and far zones. The results are a generalization of previous work [*Pure Appl. Opt.* 7, 1221 (1998)] that dealt only with the far-zone moments. These methods are applied to the problem of optimizing the so-called beam propagation factor, M_P^2.

9. **S. A. Ponomarenko and A. V. Shchegrov, "Spectral Changes of Light Produced by Scattering from Disordered Anisotropic Media", *Phys. Rev. E.* 60, 3310-3313 (1999).**

   We investigate theoretically changes in the spectrum of polychromatic light scattered by a disordered, birefringent medium. We derive an expression for the spectrum of scattered light for ordinary and extraordinary incident waves within the accuracy of the first Born approximation. Using this result, we analyze the changes in the spectrum of light due to the combined action of disorder and anisotropy in the scattering process.

10. **G. Gbur and K. Kim, "Quasi-Homogeneous Approximation for a Class of Three-dimensional Primary Sources", *Opt. Commun.* 163, 20-23 (1999).**

    We investigate the validity of the quasi-homogeneous approximation for three-dimensional primary Gaussian Schell-model sources. It is shown that the quasi-homogeneous approximation is not valid for such a source unless two conditions are satisfied, one of which depends upon the spatial characteristics of the source, and the other depends upon the wavelength of the radiation. The second of these conditions appears not to have been appreciated in previous work relating to the quasi-homogeneous approximation, and its significance to the foundations of radiometry is discussed.

11. **A. V. Shchegrov, D. Birkedal and J. Shah, "Monte Carlo Simulations of Ultrafast Resonant Rayleigh Scattering from Quantum Well Excitons: Beyond Ensemble Averaging", *Phys. Rev. Letts.* 83, 1391-1394 (1999).**

    We develop and experimentally verify novel Monte Carlo simulations of ultrafast resonant Rayleigh scattering from quantum well excitons. In contrast to existing theories, these simulations can study the dynamics and spectrum of resonant Rayleigh scattering from a single realization of disorder, and allow direct comparison to experimental data. We find excellent agreement between our experiments and simulations. Our studies demonstrate the high sensitivity of scattering dynamics to a particular realization of disorder, and provide new insights into the nature of spatial correlations of excitons.

12. **A. T. Friberg, T. D. Visser and E. Wolf, "A Reciprocity Inequality for Gaussian Schell-model Beams and Some of its Consequences", *Opt. Letts.* 25, 366-368 (2000).**

    A reciprocity inequality is derived, involving the effective size of a planar, secondary, Gaussian Schell-model source and the effective angular spread of the beam, which the source generates. It is shown to imply that a fully spatially coherent source of that class (which generates the lowest-order Hermite-Gaussian laser mode) has certain minimal properties.

13. **A. V. Shchegrov and E. Wolf, "Partially Coherent Conical Beams", *Opt. Lett.* 25, 141-143 (2000).**

    We introduce a new class of partially coherent beams that can propagate over large distances without changing their transverse profiles and their coherence properties. Such beams are generated by an incoherent superposition of identical fully coherent beams of arbitrary form, whose axes lie on a cone.

14. **E. Wolf, "Coherence of Two Interfering Beams Modulated by a Uniformly Moving Diffuser", *J. Mod. Opt.* 47, 1171-1177 (2000).**

    Coherence properties are discussed of light, which emerges from two pinholes after it has passed through a moving diffuser. The results are used to show how the correlation function of the heights of the diffuser surface and the speed with which the diffuser is moving may be determined from simple interference experiments.

15. **S. Ponomarenko and E. Wolf, "Light Beams with Minimum Phase-space Product", *Opt. Letts.* 25, 663-665 (2000).**

    We derive a reciprocity inequality involving the product of the effective size of a statistically stationary, planar, secondary source of any state of coherence and of the angular spread of the far-zone intensity generated by the source. We show that of all possible such sources, the fully spatially coherent lowest-order Hermite-Gaussian laser mode have the smallest possible reciprocity product.

16. **G. Gbur and D. F. V. James, "Unpolarized Sources that Generate Highly Polarized fields outside the source", *J. Mod. Opt.* 47, 1171-1177 (2000).**

It is demonstrated that an unpolarized primary electromagnetic source may, under special conditions, produce a field outside the source domain that is almost completely polarized in nearly all directions. This result demonstrates that the polarization statistics of a random electromagnetic field may differ significantly from the polarization statistics of the source distribution that generates it, and may in fact be quite different in different directions of observation. An example of such a source is given.

17. **A. V. Shchegrov, J. Bloch, D. Birkedal and J. Shah, "Theory of Resonant Rayleigh Scattering from Semiconductor Microcavities: Signatures of Disorder", *Phys. Rev. Letts.* 84, 3478-3481 (2000).**

We develop a self-consistent, microscopic theory of coherent resonant secondary emission from semi-conductor microcavities in the normal-mode-coupling regime. Our theory provides a quantitative description of the spectral, temporal, and angular properties of the disorder-induced emission component - resonant Rayleigh scattering - and offers an intuitive physical explanation of emission properties.

18. **T. Shirai and E. Wolf, "Transformation of Coherence and of the Spectrum of Light by a Moving Diffuser", *J. Mod. Opt.* 182, 265-272 (2000).**

Effects of a diffuser on the spectral degree of coherence and on the spectrum of light produced by transmitting light through the diffuser are described. Both stationary and uniformly moving diffusers are considered and the analysis applies to dielectric as well as to absorbing diffusers. The results are illustrated by numerical examples.

19. **A. V. Shchegrov, K. Joulain, R. Carminati and J-J. Greffet, "Near-field Spectral Effects Due to Electromagnetic Surface Excitations", *Phys. Rev. Letts.* 85, 1548-1551 (2000).**

We demonstrate theoretically that the spectra of electromagnetic emission of surface systems can display remarkable differences in the near and far zones. The spectral changes occur due to the loss of evanescent modes and are especially pronounced for systems which support surface waves.

20. **G. P. Agrawal and E. Wolf, "Propagation–induced Polarization Changes in Partially Coherent Optical Beams", *J. Opt. Soc. Amer. A* 17, 2019-2023 (2000).**

Propagation of a partially coherent optical beam inside a linear, nondispersive, dielectric medium is studied, taking into account the vector nature of the electromagnetic field. Propagation-induced polarization changes are studied by using the Gaussian-Schell model for the cross-spectral-density tensor. The degree of polarization changes with propagation and also becomes nonuniform across the beam cross section. The extent of these changes depends on the coherence radius associated with the cross-correlation function. For optical beams with symmetric spectra, the bandwidth of the source spectra is found to play a relatively minor role.

21. **T. Visser, A. T. Friberg and E. Wolf, "Phase-space Inequality for Partially Coherent Beams", *Opt. Commun.* 187, 1-6 (2001).**

A phase-space inequality is derived for beams of arbitrary state of spatial coherence. It applies to the product of a factor which expresses the effective coherence area of the source that generates the beam and the effective angular spread of the beam; and, by analogy with coherent beams, it may be regarded as a measure of the beam quality. It is found that the factor attains a minimum for the entire class of Gaussian Schell-model beams (which include the Hermite Gaussian laser mode).

22. **S. Ponomarenko and E. Wolf, "Effective Spatial and Angular Correlations in Beams of any State of Coherence and an Associated Phase-space Product", *Opt. Lett.* 26, 122-124 (2001).**

We study effective spatial and angular correlations in beams of any state of spatial coherence, and we introduce a phase-space product, Q, which takes these correlations into account. This phase-space product is shown to reduce to the conventional beam-quality factor M^2, when the beam is spatially fully coherent. We also determine the lower bound for the value of Q and demonstrate that it is attained for all Gaussian Schell-model beams.

23. **G. Gbur, "Uniqueness of the Solution to the Inverse Source Problem for Quasi-homogeneous Sources", *Opt. Commun.* 187, 301-309 (2001).**

The quasi-homogeneous approximation, often used but never rigorously justified, is carefully derived for primary three-dimensional, scalar radiation sources. The derivation indicates that nonradiating quasi-homogeneous sources do not exist. The relevance of this result and its derivation for the inverse source problem is discussed.

24. **S. Ponomarenko, "Class of Partially Coherent Beams Carrying Optical Vortices", J. Opt. Soc. Amer. A 18, 150 (2001).**

A new class of partially coherent beams with a separable phase, which carry optical vortices, is introduced. It is shown that any member of the class can be represented as an incoherent superposition of fully coherent Laguerre-Gauss modes of arbitrary order, with the same azimuthal mode index. The free-space propagation properties of such partially coherent beams are studied analytically, and their M^2 quality factor is investigated numerically.

25. **G. Gbur and E. Wolf, "Relation Between Computed Tomography (CAT) and Diffraction Tomography", *J. Opt. Soc. Amer.* A 18, 2132-2137 (2001).**

The relationship between computed tomography (CAT) and diffraction tomography (DT) is investigated. A simple condition with a clear physical meaning to derived for the applicability of CAT. Corrections due to scattering are incorporated into CAT and it is shown that the effect of scattering may be characterized by a two-dimensional fractional Fourier transform. The implications of these results for the three-dimensional imaging of weakly scattering objects are also discussed.

26. **S. Ponomarenko and E. Wolf, "Correlations in Open Quantum Systems and Associated Uncertainty Relations", *Phys. Rev. A* 63, 1-5 (2001).**

We study how correlations in a state of an open quantum system affect the intrinsic uncertainties of the expectation values of an arbitrary pair of noncommuting observables. We show that for such observables, there exists Heisenberg-type uncertainty relations that take fully into account correlations in the state of the system. If the quantum system is in a pure state, such uncertainty relations reduce to the conventional one. We obtain an equation for the density operator of a general state that minimizes the new uncertainty relations, and demonstrate that in the important case of coordinate and momentum operators, the minimum-uncertainty states are displaced squeezed thermal states.

27. **G. Gbur and E. Wolf, "The Rayleigh Range of Gaussian Schell-model Beams", *J. Mod. Opt.* 48, 1735-1741 (2001).**

The concept of the Rayleigh range, well known in the theory of coherent beams, is generalized to a class of partially coherent beams. Curves are presented which show the dependence of the Rayleigh range on the spot size of the beam and one the spectral degree of coherence of the light in the plane of the waist.

28. **A. T. Friberg, T. D. Visser, W. Wang and E. Wolf, "Focal Shifts of Converging Diffracted Waves of any State of Spatial Coherence", *Opt. Commun.* 196, 1-7 (2001).**

We analyze the focusing of wave fields of any state of coherence by systems with low Fresnel numbers. We study the optical intensity on the axis in the focal region. The dependence of the focal shift and of the maximum on-axis intensity on the state of coherence is examined for some model fields.

29. **G. Gbur and E. Wolf, "The Rayleigh Range of Partially Coherent Beams", *Opt. Commun.* 199, 295-304 (2001).**

The concept of the Rayleigh range, well known in the theory of coherent beams, is extended to partially coherent beams. A simple formula is derived, which expresses it in terms of the rms widths of the source intensity and of the intensity of the field far from the source. In the special cases when the beam is completely coherent or is of the Gaussian Schell-model type, our formula reduces to known expressions. It is also shown that a partially coherent beam will always have a Rayleigh range that is shorter than that of a fully coherent beam with the same intensity distribution in the beam waist.

30. **P. Scott Carney and E. Wolf, "Power-extinction Diffraction Tomography with Partially Coherent Light", *Opt. Lett.* 26, 1770-1772 (2001).**

Some consequences of using partially coherent fields in the recently proposed method of power-extinction diffraction tomography are analyzed. It is found that the method is very tolerant of short spectral coherence lengths. The spectral coherence length of the field is shown to set the scale of a low-pass filter that acts on the subject. The implications of these results for implementation of the method are discussed.

31. **S. Ponomarenko, "Twisted Gaussian Schell-model Solitons", *Phys. Rev. E* 64, 036618 (2001).**

We show that a certain class of spatially partially coherent solitons, namely, twisted Gaussian Schell-model solitons, exists in a logarithmically saturable nonlinear medium with a noninstantaneous temporal response. Unlike previously reported Gaussian Schell-model solitons, those discussed here carry a position-dependent twist phase, which vanishes in the fully coherent limit. We demonstrate that the presence of the twist phase provides an opportunity for controlling the degree of spatial coherence of such solitons without affecting their intensity.

32. **S. Ponomarenko, "Linear Superposition Principle for Partially Coherent Solitons", *Phys. Rev. E.* 65, 055601 (2001).**

The existence of a linear superposition principle is demonstrated for partially coherent solitons with identical intensity profiles that are supported by the same medium. Since such degenerate partially coherent solitons are generic for saturable as well as for Kerr-like nonlinear media, our results are relevant to any noninstantaneous nonlinear media. The proposed superposition principle suggests a physical interpretation of partially coherent solitons as generalized linear modes of their self-induced waveguides. The power of such a superposition principle is illustrated by identifying soliton structures with controllable coherence properties both in logarithmically saturable and in Kerr-like nonlinear media.

33. **G. Gbur, T. D. Visser and E. Wolf, "Anomalous Behavior of Spectra near Phase Singularities of Focused Waves", *Phys. Rev. Lett.* 88, 013901-1 - 013901-4 (2002).**

It is shown that remarkable spectral changes take place in the neighborhood of phase singularities near the focus of a converging, spatially fully coherent polychromatic wave diffracted at an aperture. In particular, when the spectrum of the wave in the aperture consists of a single line with a narrow Gaussian profile, the spectrum near a phase singularity (i.e., near points of zero intensity of some particular spectral component) changes drastically along a closed loop around the singularity. The spectrum is redshifted at some points, blueshifts at otheres, and is split into two lines elsewhere.

34. **S. Ponomarenko and E. Wolf, "Universal Structure of Field Correlations within a Fluctuating Medium", *Phys. Rev. E.* 65, 016602 (2002).**

We study the structure of the second-order correlation function of scalar wavefields, which are generated by statistically stationary sources, fluctuating within a homogeneous dissipative medium. We derive a closed-form analytical expression for the spectral degree of coherence of the wavefield. If the dissipation in the medium is sufficiently small, and the source fluctuations are statistically isotropic, the degree of spatial coherence of the field produced by any such source is shown to be proportional to the imaginary part of the Green's function of the system, with a proportionality factor depending on the dimensionality of the field. The result holds for wavefields in both three and two spatial dimensions, but not in one dimension. We discuss the physical nature of such universal forms of the spectral degree of coherence.

35. **T. Shirai and E. Wolf, "Spatial Coherence Properties of the Far Field of a Class of Partially Coherent Beams which have the same Directionality as a Fully Coherent Laser Beam", *Opt. Comm.* 204, 25-31 (2002).**

Spatial coherence properties are examined of the far fields produced by partially coherent Gaussian Schell-model sources which generate the same distributions of radiant intensity as a fully coherent single-mode laser. The results are illustrated by numerical examples.

36. **G. Gbur and E. Wolf, "The Spreading of Partially Coherent Beams in Random Media", *J. Opt. Soc. Amer. A* 19, 1592-1598 (2002).**

Some published computational work has suggested that partially coherent beams may be less susceptible to distortions caused by propagation through random media than fully coherent beams. In this paper this suggestion is studied quantitatively by examining the mean squared width of partially coherent beams in such media as a function of the propagation distance. The analysis indicates under what conditions, and to what extent, partially coherent beams are less affected by the medium.

37. **G. Gbur, T. D. Visser and E. Wolf, "Singular Behavior of the Spectrum in the Neighborhood of Focus", *J. Opt. Soc. Amer. A.* 19, 1694-1700 (2002).**

In a recent paper [*Phys. Rev. Lett.* **88**, 013901 (2002)] it was shown that when a convergent spatially coherent polychromatic wave is diffracted at an aperture, remarkable spectral changes take place on axis in the neighborhood of certain points near the geometrical focus. In particular, it was shown that ht spectrum is redshifted at some points, blueshifted at others, and split into two lines elsewhere. In the present paper we extend the analysis and show that similar changes take place in the focal plane, in the neighborhood of the dark rings of the Airy pattern.

38. **S. A. Ponomarenko, J.-J. Greffet and E. Wolf, "The Diffusion of Partially Coherent Beams in Turbulent Media", *Opt. Commun.* 208, 1-8 (2002).**

We study the spreading of the rms spatial and angular characteristics of partially coherent beams in turbulent media. The angular broadening of the beam is shown to be diffusion-like. The dynamics of the rms width of the beam is found to be determined by the interplay of free-space diffraction and turbulent diffusion. Our results indicate the conditions under which partially coherent beams are less sensitive to distortions caused by the atmospheric turbulence than are fully coherent beams.

39. **S. A. Ponomarenko and E. Wolf, "Spectral Anomalies in a Fraunhofer Diffraction Pattern", *Opt. Lett.* 27, 1211-1213 (2002).**

We show that spectacular spectral changes take place in the vicinity of the dark rings of the Airy pattern formed with spatially coherent, polychromatic light diffracted at a circular aperture.

40. **G. Gbur and E. Wolf, "Diffraction Tomography without Phase Information", *Opt. Letts.* 27, 1890-1892 (2002).**

A modified form of diffraction tomography is presented in which measurements of the phase of the scattered field are replaced with measurements of the intensity on two planes beyond the scatterer. The new method is illustrated by example.

41. **E. Wolf and G. Gbur, "Determination of the Scattering Amplitude and of the Extinction Cross-section from Measurements at Arbitrary Distances from the Scatterer",** ***Phys. Letts. A*** **302, 225-228 (2002).**

    It is shown that the scattering amplitude for any direction of incidence and any direction of scattering and, consequently, also the extinction cross-section, of a scattering object may be determined from measurements of the scattered field over a plane at an arbitrary distance from it.

42. **T. D. Visser, G. Gbur and E. Wolf, "Effect of the State of Coherence on the Three-Dimensional Spectral Intensity Distribution near Focus",** ***Opt. Commun.*****, 213, 13-19 (2002).**

    The effect of spatial coherence on the three-dimensional spectral intensity distribution in the focal region of a system with a high Fresnel number is investigated. The structure of a Gaussian Schell-model field is studied in detail.

43. **G. Gbur and E. Wolf, "Hybrid Diffraction Tomography without Phase Information",** ***JOSA A*** **19, 2194-2202 (2002).**

    We introduce a hybrid tomographic method, based on recent investigations concerning the connection between computed tomography and diffraction tomography that allows direct reconstruction of scattering objects from intensity measurements. This technique is non-iterative and is intuitively easier to understand and easier to implement than some other methods described in the literature. The manner in which the new method reduces to computed tomography at short wavelengths is discussed. Numerical examples of reconstructions are presented.

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In addition to Professor Emil Wolf, the Principal Investigator for this grant, the following scientists have taken part in this research:

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